NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.

REPORT NUMBER 1058

THE EFFECTS OF BIMODAL PRESENTATION OF STIMULI AND NOISE ON TARGET DETECTION

by

Lawrence J. Lewandowski
and
David A. Kobus

Naval Medical Research and Development Command
Research Work Unit M0100.001-1021

Released by:

William C. Milroy, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

1 August 1985

THE EFFECTS OF BIMODAL PRESENTATION OF STIMULI AND NOISE ON TARGET DETECTION

By

Lawrence J. Lewandowski, Ph.D.
David A. Kobus,, Ph.D., LT, MSC, USNR

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
REPORT NUMBER 1058

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Work Unit M0100.001-1021

Approved and Released by

W. C. MILROY, CAPT MC USN
COMMANDING OFFICER
NAVSUBMEDRSCHLAB

SUMMARY PAGE

PROBLEM

To determine if auditory, visual or the bimodal approach is best for the detection of simple (single tone) stimuli.

FINDINGS

Redundant signals in two modalities, as opposed to a single signal in one modality, collectively improved sensitivity and reduced uncertainty of an operator regarding a choice response, thus providing a reduction in detection threshold. Detection threshold to a target was not negatively affected when attention was divided between two modalities and noise was presented in both.

APPLICATION

The finding of improved detection in each modality of the bimodal condition supports the advantage of a bimodal input approach in tasks which involve bisensory stimulation such as sonar, radar, and ECM.

ADMINISTRATIVE INFORMATION

This research was conducted as part of Naval Medical Research and Development Command Work Unit M0100.001-1021 - Auditory Sonar. It was submitted for review on 22 July '85, approved for publication on 1 Aug '85, and designated as NSMRL Report No. 1058.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

ABSTRACT

Twenty men were presented background noise and target stimuli in either the visual or auditory modality, or in both at once. Auditory and visual detection thresholds were lowest when functionally redundant targets were presented simultaneously in both modalities. It appeared that two redundant signals collectively improved sensitivity and reduced uncertainty regarding a choice response, thus enabling a reduction in detection threshold. Detection threshold to a single target was not negatively affected when attention was divided between two modalities and noise was presented in both. The finding of improved detection in each modality of the bimodal condition is consistent with the coactivation explanation of bimodal facilitation and supports the advantage of a bimodal input approach in tasks such as sonar, radar, and air traffic control.

INTRODUCTION

Many investigators have found that response speed and/or sensitivity are enhanced when individuals respond to two sources of redundant information rather than just one.[1-4] This "redundant signals" effect has been reported in numerous one-modality studies in which two identical stimuli are simultaneously presented. Most commonly, these studies involve visual letter detection.[3,5-7] In addition, some studies have examined the redundant signals effect by presenting redundant information simultaneously via two modalities.[2,3,8-12] In these studies the presentation of functionally redundant signals in two modalities resulted in a response gain (i.e., decreased reaction time or detection threshold) over at least one of the two modalities; however, when stimulus information was different in each modality or required separate responses or multiple targets were used, a response decrement resulted.

A variety of studies have investigated the effects of presenting target stimuli bimodally, and found that a response to a redundant signal may be more sensitive or faster than a response to either single source of information.[1,3,13-15] Nickerson[4] referred to this effect as "energy summation," whereby two stimulus energies are combined in such a way that the total energy is equivalent to increasing the intensity of one stimulus alone. Miller[3], Shaw[15], and others have argued that rather than independent activations within each channel, information from two attended modalities is integrated and results in "coactivation." They have suggested that combined activation occurs after a coding stage but prior to a decision stage, and builds at a faster rate than activation from either modality alone, thus accounting for the redundant signals effect.

Perhaps the strongest evidence for a bimodal redundant signals effect comes from studies on detectability of two signals in the threshold region. Some detection studies have obtained improved performance by using short-duration bimodal stimulus presentations,[2,16-17] whereas others have obtained improved detection in vigilance paradigms.[12,18-19] Of these studies, Colquhoun[13] attempted to simulate actual sonar displays in a vigilance study of single and dual-modality performance. He found detection to be best when auditory and visual displays were monitored concurrently, and that auditory was better than visual detection when comparing single modes. Kobus, et al.[11] studied detection performance on actual sonar equipment using a complex sonar task. They had subjects detect and classify five targets masked by noise in one or both modalities, and did not direct the subjects' attention. They found no difference between the bimodal condition and the better single modality. Possible reasons for the lack of bimodal facilitation are the large number of targets used, and the uncertainty associated with where the target(s) would be presented.

It is common in an operational setting (i.e., sonar, radar, air traffic control) for an operator to have to deal with information in two modalities; the information may be either redundant or not, and presented in various noise backgrounds. Having to divide his attention, whether the signals are redundant or not, the amount of information, and the noise can

all influence his performance. But the effects when these variables impinge simultaneously is still not well understood.

The purpose of this study was to examine differences between unimodal and bimodal presentation of signal information on detection when the target information was presented in a complex task such as sonar with continually updated displays. In this task the effect of target redundancy was examined as subjects were required to detect and classify targets when their attention was either focused on one modalitiy or divided between two modalities.

It was hypothesized that detection threshold would be improved when redundant information was presented in both modalities at once (bimodal condition) compared to the situation in which information was presented to only one modality to which attention was focused (baseline conditions), or to the situation in which information was presented to only one modality but the subject was forced to divide his attention between two modalities (unimodal conditions). Further, it was hypothesized that detection would be degraded when the subject was presented with information in one modality but required to attend to both modalities (unimodal conditions) compared to the situation in which he could focus on one modality (baseline conditions).

METHOD

Subjects

Twenty-three men ages 18 to 24 years volunteered to participate. All had or were corrected to 20/20 visual acuity and displayed hearing within the normal range in routine audiometric testing.

Apparatus

Visual and auditory signals were initiated by a Wavetek programmable synthesized function generator (model 278) and displayed via a monochromatic visual display unit (VDU) and Koss (pro 4-AAA) headphones. The generated signal was split into two channels and fed through separate attenuators prior to display. The noise source consisted of pre-recorded ambient sea noise played on a Hewlett-Packard (3964A) instrumentation recorder. The noise signal also was split into two channels and routed through separate attenuators to the monitor and headphones.

The visual display provided signal frequency along the x-axis and time along the y-axis. Visual noise appeared as random lighted pixels varying in intensity. Amplitude of the signal was represented along the z-axis which controlled the intensity of each pixel. A horizontal line of pixels appeared at the top of the display and moved in a "waterfall" fashion down the screen (16 lines present at a time), such that each line was visible for 6.2 seconds. A visual target was presented at either 600 Hz, on the left side of the display, or 1700 Hz, on the right side of the display. The target appeared as an intermittent vertical arrangement of dots of greater intensity than the background noise. The amplitude of the visual noise was

60 dB. The amplitude of the visual signal initially was attenuated to below threshold level, and attenuation was decreased until detection occurred. Visual detection was measured in terms of dB of attenuation.

The amplitude of the auditory noise was 60 dB. Targets were either a 600 Hz or 1700 Hz frequency signal providing a low or high intermittent tone. Targets were presented as tone bursts triggered at a 2 Hz rate with a 2 ms pulse width. The auditory signal also was attenuated well below threshold. Attenuation was decreased until detection occurred, as measured by dB level.

Procedure

Target thresholds were measured under three basic conditions. In the baseline condition, only one sensory modality was stimulated; target information and noise were presented either as a visual display or through earphones and attention was focused on the presented modality. In the unimodal condition, the noise was presented to both attended modalities, but the target information was presented in only one of the modalities. In the bimodal condition, the same target information and noise were presented to both attended modalities at the same time.

Subjects were tested under five conditions: (1) auditory target with auditory noise (auditory baseline); (2) visual target with visual noise (visual baseline); (3) auditory target with both auditory and visual noise (auditory unimodal); (4) visual target with both visual and auditory noise (visual unimodal); (5) both visual and auditory target with both visual and auditory noise (auditory and visual bimodal).

After a brief description of the procedures and a training procedure, the subjects received two practice trials in each condition with feedback as to the correctness of their responses. The baseline conditions were presented first to all subjects as blocks of trials in counterbalanced order. The unimodal and bimodal conditions were intermixed and presented randomly. The subjects were not told which condition was being presented. There were 30 trials, six per condition. Each trial took about one minute to complete.

Targets were presented below threshold, and their attenuation was decreased by 1 dB every 6.2 seconds (that is, their intensity was increased) until the subject reported hearing a low or high tone and/or seeing a vertical line on the left or right of the VDU. In the bimodal condition, attenuation was decreased simultaneously for both the visual and auditory presentation until the subject correctly reported the target in both modalities.

Both the dB level of attenuation as well as the classification accuracy was recorded for each target detection. The classification data were used to eliminate subjects who were guessing and to determine if modality preferences existed in the bimodal condition.

RESULTS

It was decided to eliminate any subjects whose classification error rate exceeded 25%. Three of the 23 subjects were therefore eliminated, and their data were excluded from the analysis. The average error rate of the remaining subjects was 11%.

Levels of attenuation (dB) across targets were converted to means for each of the five conditions. Difference scores were determined by subtracting the mean attenuation of the target at threshold when only one modality was presented and attention was focused (baseline) from the mean attenuation at threshold when both modalities were presented and attention was divided. Table I shows these difference scores.

Table I. Mean Difference Scores Of Unimodal and Bimodal Conditions From Baseline (dB of attenuation)

	Conditions		
Modality	Unimodal	Bimodal	Advantage
Auditory	-.184	.942	1.126 **
Visual	-.504	1.123	1.627 **

** p .01

When subjects were monitoring two modalities and were presented an auditory target, their performance was similar to baseline. They were a little less sensitive to the target (-.184 dB) in this condition, but the difference was not significant. Similarly, the mean attenuation at threshold of the visual signal when subjects monitored two modalities was not significantly different from baseline (-.504 dB). In other words, the change from focused attention to divided attention when only one target was presented did not significantly degrade detection performance.

When the same target was presented in both modalities (bimodal), Table I shows that the mean attentuation at threshold of the auditory target was .942 dB greater than when it was presented only as an auditory signal. That is, the target was detected at a lower threshold when it was accompanied by the presentation of the visual display. This increase in detectability when both targets were presented, compared to the condition in which only the auditory signal was presented and there was no visual signal in the visual noise, was highly significant (F (1,19)=18.66, $p<.01$).

Similarly, in that condition the attenuation of the visual signal was 1.123 dB greater than when it was presented only as a visual signal. Again, the visual signal was detected at a much lower threshold when it was accompanied by the auditory presentation. The increase in detectability when both targets were presented (bimodal) compared to the condition in which only the visual signal was presented and there was no auditory signal in the auditory noise (unimodal) was highly significant (F (1,19)=18.66, $p<.01$).

Auditory detection was better for 15 of the 20 subjects, and visual detection was better for 17 of the 20 subjects in the bimodal condition, when two redundant targets were presented at the same time than when only one target was presented.

DISCUSSION

The results of this study support the major hypothesis that bimodal presentation of a redundant target reduces detection threshold over single target, unimodal presentations. Detection of both auditory and visual targets was enhanced in the bimodal condition, regardless of the modality in which the target was first perceived by the subjects. These findings are similar in nature to those reported in vigilance studies[18-19] and detection studies which employed redundant, meaningful information.[2,9]

Since both modalities showed an enhancement of detection performance when the stimuli were presented simultaneously, we cannot conclude that one stimulus acts as an accessory for another. Rather, the integration of two redundant signals in the bimodal condition prior to a response seemed to increase the subject's sensitivity and certainty that a particular target had been presented. Thus, at a given intensity, two redundant signals presented to different modalities reduced response uncertainty and led to more efficient performance than when a target was presented to a single modality. Adams and Chambers,[20] Corcoran and Weening,[21] and Duncan[22] formulated similar interpretations based on their experiments.

The hypothesis that monitoring an additional modality containing background noise would negatively affect detection of a single target was not supported statistically. Subjects were able to move from focused attention on one modality to divided attention across two modalities, both with background noise, without a significant decrement in performance. This finding is consistent with the work of Mulligan and Shaw,[14] and suggests that increasing the number of modalities to be monitored is not the same as increasing the set size of target information, at least in regard to two modalities.

In this study, detection performance on a simulated sonar task was not negatively affected when a second modality containing background noise was introduced and attention was divided. In fact, performance increased for both auditory and visual detection when redundant targets were presented in each modality simultaneously. Both of these findings support a bimodal approach to sonar operation and similar types of signal processing tasks. Whether these results would replicate using other dependent measures (i.e., reaction time), different types of stimuli, and under varying task loading or time sharing conditions will need to be explored, particularly in regard to such operations as sonar, radar, and air traffic control.

ACKNOWLEDGMENTS

The authors would like to thank Saul Luria and David Neri for their helpful comments concerning this research; Susan Carpenter, Cindy Mitchell, and John Wojtowicz for audiometric screening; STSC John Wilson for providing the sonar equipment; Alma Ryan for clerical assistance; and HN Tim Potter for his technical assistance.

REFERENCES

1. Hershenson, M. (1962). Reaction time as a measure of intersensory facilitation. Journal of Experimental Psychology, 63, 289-293.

2. Loveless, N.E., Brebner, J. & Hamilton, P. (1970). Bisensory presentation of information. Psychological Bulletin, 73, 161-199.

3. Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. Cognitive Psychology, 14, 247-279.

4. Nickerson, R.S. (1973). Intersensory facilitation of reaction time: Energy summation or preparation enhancement? Psychological Review, 80, 489-509.

5. Burns, D. (1979). A dual-task analysis of detection accuracy for the case of high target-distractor similarity: Further evidence for independent processing. Perception & Psychophysics, 25, 185-196.

6. Eriksen, C.W. & Eriksen, B.A. (1979). Target redundancy in visual search: Do repetitions of the target within the display impair processing? Perception & Psychophysics, 26, 195-205.

7. Kinchla, R.A. (1974). Detecting target elements in multielement arrays: A confusability model. Perception & Psychopysics, 15, 149-158.

8. Grice, G.R., Canham, L. & Boroughs, J.M. (1984). Combination rule for redundant information in reaction time tasks with divided attention. Perception & Psychophysics, 35, 451-463.

9. Halpern, J. & Lantz, A.E. (1974). Learning to utilize information presented over two sensory channels. Perception & Psychophysics, 16, 321-328.

10. Hanson, V.L. (1981). Processing of written and spoken words: Evidence for common coding. Memory and Cognition, 9, 93-100.

11. Kobus, D.A., Russotti, J., Schlichting, C., Haskell,G., Carpenter, S. & Wojtowicz, J. (1985). Detection and recognition performance of sonar operators in a multimodal task. Naval Submarine Medical Research Lab Report No. 1046, Groton, Ct.

12. Lewandowski, L.J., Hursh, S. & Kobus, D A. (1985). Multimodal versus unimodal information processing of words. Naval Submarine Medical Research Lab Report 1056, Groton, Ct.

13. Colquhoun, W.P. (1975). Evaluation of auditory, visual, and dual-mode displays for prolonged sonar monitoring in repeated sessions. Human Factors, 17, 425-437.

14. Mulligan, R.M. & Shaw, M.L. (1981). Attending to simple auditory and visual signals. Perception & Psychophysics, 30, 447-454.

15. Shaw, M.L. (1982). Attending to multiple sources of information: The integration of information in decision making. Cognitive Psychology, 14, 353-409.

16. Brown, A. E. & Hopkins, H. K. (1967). Interaction of the auditory and visual sensory modalities. Journal of the Acoustical Society of America, 41, 1-6.

17. Fidell, S. (1970). Sensory function in multimodal signal detection. Journal of the Acoustical Society of America, 47, 1007-1015.

18. Baker, R.A., Ware, J.R. & Sipowicz, R.R. (1962). Vigilance: a comparison in auditory, visual, and combined audio-visual tasks. Canadian Journal of Psychology, 16, 192-198.

19. Osborn, W.C., Sheldon, R.W. & Baker, R.A. (1963). Vigilance performance under conditions of redundant and nonredundant signal presentation. Journal of Applied Psychology, 47, 130-134.

20. Adams, J.A. & Chambers, R.W. (1962). Response to simultaneous stimulation of two sense modalities. Journal of Experimental Psychology, 47, 130-134.

21. Corcoran, D.W.J. & Weening, D.L. (1969). On the combination of evidence from the eye and ear. Ergonomics, 12, 383-394.

22. Duncan, J. (1980). The locus of interference in the perception of simultaneous stimuli. Psychological Review, 87, 272-300.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NSMRL Report No. 1058	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE EFFECTS OF BIMODAL PRESENTATION OF STIMULI AND NOISE ON TARGET DETECTION		5. TYPE OF REPORT & PERIOD COVERED Interim report 6. PERFORMING ORG. REPORT NUMBER NSMRL Report No. 1058
7. AUTHOR(s) LAWRENCE J. LEWANDOWSKI, DAVID A. KOBUS		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, Connecticut 06349		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 65856N M0100.001-1021
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Submarine Medical Research Laboratory Naval Submarine Base New London Groton, Connecticut 06349		12. REPORT DATE 1 August 1985 13. NUMBER OF PAGES 7
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Medical Research and Development Command Naval Medical Command, National Capital Region Bethesda, Maryland 20814		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

target detection; stimuli; visual modality; auditory modality;

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Twenty men were presented background noise and target stimuli in either the visual or auditory modality, or in both at once. Auditory and visual detection thresholds were lowest when functionally redundant targets were presented simultaneously in both modalities. It appeared that two redundant signals collectively improved sensitivity and reduced uncertainty regarding a choice response, thus enabling a reduction in detection threshold. Detection threshold to a single target was not negatively affected when attention was

20. continued
divided between two modalities and noise was presented in both. The finding of improved detection in each modality of the bimodal condition is consistent with the coactivation explanation of bimodal facilitation and supports the advantage of a bimodal input approach in tasks such as sonar, radar, and air traffic control.